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Effect of modulated at different low frequencies microwave radiation on human EEG

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Abstract This study is aimed to clarify whether effect of low-level microwave radiation on human brain differs at different modulation frequencies. Resting EEG recordings were done on different groups of healthy volunteers. The 450 MHz microwave radiation modulated at 40 and 70 Hz (15 subjects) and 217 and 1,000 Hz (19 subjects) frequencies was applied. The results of our previous study at 7, 14 and 21 Hz modulation were included into analysis. Ten cycles of the exposure (1 min off and 1 min on) at each fixed modulation frequencies were applied. The field power density at the scalp was always 0.16 mW/cm^2. Our results showed that microwave exposure increased the EEG energy at EEG frequencies lower or close to the modulation frequency. No effect was detected at EEG frequencies higher than the modulation frequency. Statistically significant changes were caused by exposure in the EEG alpha and beta frequency bands; no significant effect was detected in the theta band. Our results suggest that telecommunication devices with complex spectrum of modulation frequencies like mobile phone can affect all human EEG frequency bands.

Keywords EMF effect · Modulation · Microwave radiation · EEG rhythms · Frequency dependence

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1 Introduction

The increasing applications of telecommunication devices have aroused problem of possible radio-frequency electromagnetic field (EMF) effects on human brain physiology (Cook et al. 2006; Huber et al. 2002, 2005; Hinrikus et al. 2008a, b; Bachmann et al. 2005; Curcio et al. 2005). Telecommunication devices use modulated microwave radiation. Modulation has been shown to play crucial role in microwave effects on EEG and cerebral blood flow: only modulated microwave radiation produced changes in human EEG and cerebral blood flow intensity (Huber et al. 2005).

Despite of many studies on the effect of low-level radio-frequency EMF on human nervous system, the mechanisms behind the effects are still unclear. Problem about the effects at different EMF frequencies is still open. Therefore, difficulties appear in independent repeating of the experimental results and even doubts arise in low-level EMF effects.

The radio-frequency EMF field cannot cause any regular changes in the ions movement due to inertial properties and viscosity of the liquid medium. Therefore, the frequency dependence can rather be related to the modulation than to the radio frequency.

The signals of cellular phones have complex spectrum and are modulated inside a wide low-frequency band. Differences of the effects caused by separate modulation frequencies cannot be distinguished in the case of experiments with cellular phone as a radio-frequency EMF source. Special studies employed other EMF sources, but usually only one modulation frequency was used. Unfortunately, the results achieved at different modulation frequencies in different experimental studies are not comparable due to the diversity of experimental conditions.

In our previous study, the modulation frequencies 7, 14 and 21 Hz were selected inside the physiological spectrum of the EEG rhythms. Alterations in the EEG power at modulation frequencies higher or close to the EEG rhythm frequency bands were reported (Hinrikus et al. 2008a). However, changes in the EEG were detected also at the main spectral component of mobile phone modulation 217 Hz, much higher than the EEG spectrum frequency (Bachmann et al. 2005).

The aim of this study was to evaluate the effect of microwaves modulated at different modulation frequencies higher than the physiological spectrum of the human EEG rhythms. To accomplish this purpose, experiments at modulation frequencies 40, 70, 217 and 1,000 Hz were performed and analysed including the results of our previous study at modulation frequencies 7, 14 and 21 Hz. Relative changes caused by modulated microwaves in power of the EEG theta, alpha and beta rhythms were selected as a measure.

2 Method and equipment

2.1 Subjects

The experiments were done on two groups of healthy volunteers. The first group consisted of 15 young persons (aged 21–24), 8 males and 7 females, and the second group of 19 young persons (aged 21–24), 8 males and 11 females.

All the subjects selected were without any medical or psychiatric disorders. A questionnaire and a clinical interview were used to evaluate their physical and mental conditions (tiredness and sleepiness) before the experiment. The persons who declared tiredness or sleepiness before the experiment were excluded. After the recordings, they were asked how they were feeling during the experiment. The subjects reported neither alertness nor any strain experienced during the recordings. The experiments were conducted with understanding and written consent of each participant.

The room of experiment was dark and the subjects were lying in a relaxed position, eyes closed and ears blocked during the experiments.

All subjects passed the experimental protocols with exposure and sham. The subjects were not informed of their exposure during the experiment; however, they were aware of the possibility of being exposed. During each double-blind test session, the exposed and sham-exposed subjects were randomly assigned by computer. A computer also randomly assigned the succession of modulation frequencies. Only one experimental EEG recording was performed for a subject during a day between time interval 9.00 am to noon.

The study was conducted in accordance with the Declaration of Helsinki and was formally approved by the local Medical Research Ethics Committee.

2.2 Microwave exposure

Microwave exposure was selected identical to that in our previous studies (Hinrikus et al. 2008a, b). The only exception from our previous studies was that different modulation frequencies were applied: 40 and 70 Hz for the first and 217 and 1,000 Hz for the second group of subjects. Exposure conditions were the same for all subjects in the group.

The 450 MHz electromagnetic radiation was generated by the Rhode & Swartz signal generator model SML02. The RF signal was 100% pulse-modulated by the pulse modulator SML-B3, duty cycle 50%. The signal from generator was amplified 30 dB by the power amplifier. The generator and amplifier were carefully shielded. The 1 W electromagnetic radiation output power was guided by a coaxial lead to the 13 cm quarter-wave antenna, located 10 cm from the skin on the left side of the head.

The spatial distribution of the electromagnetic radiation power density was measured by the Fieldmeter C.A 43 field strength meter. The measurements were performed by the Central Physical Laboratory of the Estonian Health Protection Inspection. During the experiments, the stability of the electromagnetic radiation level was monitored by the IC Engineering Digi Field C field strength meter. Estimated from the measured calibration curves, the average field power density of the modulated microwave at the skin from the left side of the head was 0.16 mW/cm^2.

2.3 Recording protocol and equipment

Our experimental study was performed according to the recording protocol applied in our previous studies (Hinrikus et al. 2008a; Bachmann et al. 2005). All subjects passed the sessions with microwave exposure and sham.

The protocol with exposure lasted 40 min, during which the resting eyes closed EEG was continuously recorded. The subject was exposed to microwave at fixed modulation frequency during every even minute of the recording. The pair of successive reference minute followed by exposed minute constituted an exposure cycle. Twenty exposure cycles were applied during the recording. The first ten exposure cycles were performed at one and the last ten at second modulation frequency. Selection of 40 or 70 Hz and 217 or 1,000 Hz as first or second modulation frequency was randomly assigned. Sham recording session used the same protocol, except that the microwave power was switched off.

For the EEG recordings, the Cadwell Easy II EEG measurement equipment was used. The EEG was recorded using nine electrodes, which were placed on the subject's head according to the international 10–20-electrode position classification system. The channels for analysis were chosen to cover the entire head: frontal—FP1, FP2; temporal—T3, T4; parietal—P3, P4; occipital—O1, O2 and the reference electrode Cz. The EEG recordings were stored on a computer with a 400 Hz sampling frequency.

2.4 EEG analysis

Relative changes in the recorded EEG signal between the cycle segments with and without exposure were selected as a measure for detection of the microwave effect on the EEG energy.

Initially, the total EEG frequency band 0.5–48 Hz was selected in the EEG recorder. The powers of four basic EEG frequency bands: theta (4–6.8 Hz), alpha (8–13 Hz), beta1 (15–20 Hz) and beta2 (22–38 Hz) were extracted from the total EEG by filtering. Elliptic bandstop filters with an attenuation of 50 dB in the stopband were used. Such a selection of the EEG frequency bands excluded applied modulation frequencies and possible related artifacts from the analysis.

The pre-processing of the signals was performed in the LabVIEW programming and signal-processing environment. The energies of the different EEG rhythms were analysed separately.

Next, the average energies for segments with and without microwave exposure were compared. Comparison intervals were selected as the first 30 s from the beginning of reference segment and microwave exposed segment of each exposure cycle.

The average energy of an arbitrary comparison interval was calculated as follows:

$$s_i = \frac{1}{N}\sum_{r=1}^{N}[x(r)]^2, \qquad (1)$$

where x is the amplitude of the recorded signal and N is the number of samples, during 30 s $N = 12{,}000$. The relative change in the energy of the recording segments with and without microwave exposure was selected for further analysis. Finally, parameter S_c for a cycle was calculated as follows:

$$S_c = \left(\frac{s_2}{s_1} - 1\right) \times 100\%, \qquad (2)$$

where s_1 and s_2 were the average energies inside the comparison segments without and with microwave exposure, respectively. For sham recordings, the same parameter was calculated for comparison segments as first 30 s of even and first 30 s of odd minutes of the recordings.

The effect of a microwave exposure was estimated by averaging the values of parameter S_c over ten cycles of exposure at the fixed modulation frequency and over all subjects in the group. Our previous studies did not reveal significant differences between relative changes in different channels (Hinrikus et al. 2008a). Therefore, data in P3–P4 channels were selected for analysis.

In the statistical analysis, each EEG frequency band (theta, alpha, beta1 and beta2) was considered separately. The Bonferroni correction for multiple comparisons was applied with a 0.05 confidence level.

3 Results and discussion

Graphs of relative changes caused by microwave exposure at different modulation frequencies in the EEG power in P3–P4 channels for all groups are presented in Fig. 1.

Obvious is increase in all graphs (except EEG theta band) at all modulation frequencies (except 1,000 Hz) compared with sham exposure. The highest increase occured in the EEG alpha band at modulation frequencies 14 and 21 Hz. This effect is supported by findings reported by other authors: the exposure to pulse-modulated 900 MHz has been reported to enhance the sleep and waking EEG power in the alpha frequency range (Huber et al. 2002; Curcio et al. 2005). Most steady is the increase in the EEG beta band at different modulation frequencies.

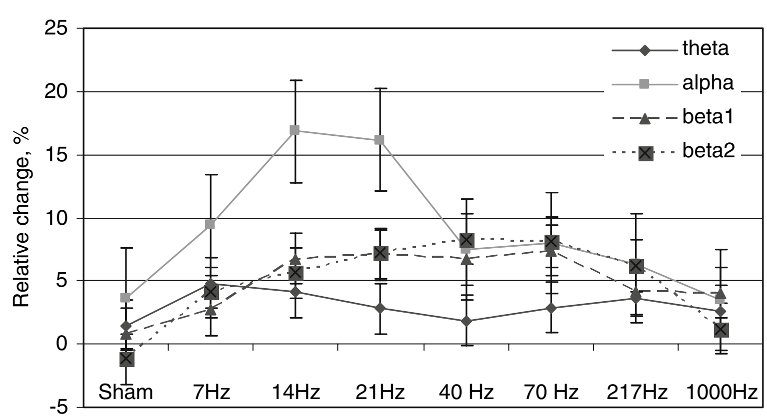

Fig. 1 Calculated values of S-parameter in P3–P4 channels averaged over a group at different fixed modulation frequencies

Remarkable is good matching between changes in the EEG beta frequency bands in different groups despite the subjects within the groups were different. So the relative changes at modulation frequencies 14 and 21 Hz based on the results from our previous study (Hinrikus et al. 2008a) have values close to these received in this study at 40 and 70 Hz modulation frequencies for the first group of subjects. Furthermore, the changes at 217 Hz modulation frequency based on the results of this study on the second group of subjects have approximately the same value.

Averaged values for *S*-parameters at different modulation frequencies are presented in Table 1. The same parameters calculated for recordings with sham exposure are provided for comparison. Statistically significant changes occur in the EEG alpha band at 14 and 21 Hz modulation, in the beta1 band at 14, 21, 40 and 70 Hz modulation and in the beta2 band at 21, 40, 70 and 217 Hz modulation. It seems characteristic that with increase in the modulation frequency, the frequency of the affected EEG band also rises.

Exposure to microwave leads to increase in the EEG power in all affected EEG frequency bands and at all modulation frequencies. Statistically significant changes occurred at modulation frequencies close or higher that the EEG rhythm frequency. No significant changes were revealed at 7 and 1,000 Hz modulation frequencies. The EEG theta rhythm was not affected by microwave exposure.

As we can see from the results presented above, different modulation frequencies affect different EEG frequency bands. The relationship between the excited EEG frequency band and the modulation frequency is presented in Fig. 2.

This graph shows clearly that the modulation frequency should be within the EEG frequency band expected to be excited or higher. High-frequency limit (higher frequency of the affected EEG band) at 40, 70 and 217 Hz modulation is caused by the EEG analysis: the highest EEG frequency band for analysis beta2 was selected, 22–38 Hz. It seems possible that microwave exposure modulated at the frequency higher than the EEG spectrum is able to affect all EEG rhythms. Only exception might be theta rhythms. Possible reasons can be more deep location of theta rhythm sources inside the brain as well as more stable mode of operation.

4 Conclusion

Our results showed that 450 MHz microwave exposure modulated at 14, 21, 40, 70 and 217 Hz caused significant increase in the EEG alpha and beta rhythms energy. The EEG frequencies lower or close to the modulation frequency were affected by modulated microwave radiation. No significant effect was detected at EEG frequencies higher than the modulation frequency.

Table 1 Calculated relative changes in P3–P4 channels at different modulation frequencies averaged over a group

	Sham1	7 Hz	14 Hz	21 Hz	Sham2	40 Hz	70 Hz	Sham3	217 Hz	1,000 Hz
Theta	5.33	4.85	4.16	2.82	1.93	1.84	2.86	1.51	3.68	2.66
Alpha	3.33	9.41	16.8*	16.2*	4.45	7.53	7.99	3.62	6.37	3.51
Beta1	1.32	2.66	6.74*	7.07*	0.87	6.73*	7.47*	0.81	4.24	4.04
Beta2	0.79	4.12	5.63	7.17*	−0.77	8.31*	8.17*	−1.23	6.24*	1.28

The statistically significant differences ($p < 0.05$ after Bonferroni correction) between sham and exposed results marked*

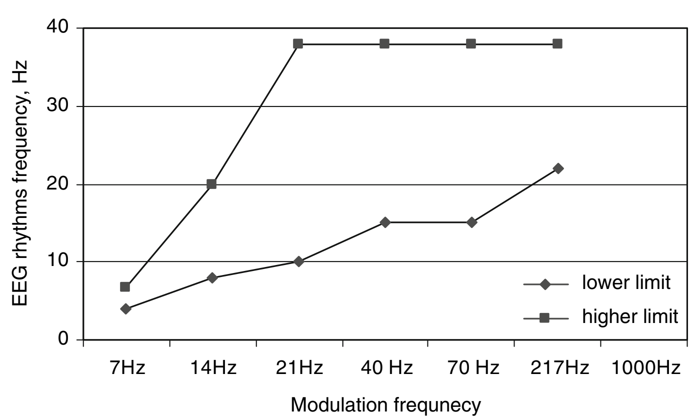

Fig. 2 Dependence of the excited EEG rhythms frequency on the modulation frequency. *Marked points* denote the highest and the lowest frequency of the excited EEG frequency bands

Our results suggest that telecommunication devices with complex spectrum of modulation frequencies like mobile phone can affect all EEG frequency bands.

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